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EFFECT OF RESIDUAL PHOSPHORUS ON CROP PRODUCTION

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THE recently enough work had not been done in India on the residual effect of phosphatic fertilizers on Indian Soils. This handy bulletin attempts to bring out the importance of the subject and summarise the results of the experiments conducted so far. The technical as well as economic aspects of residual phosphorus such as the extent of its carry-over to the subsequent crops, relationship of soil type with the quantum of response and comparative values of the various forms of phosphates have been discussed in a matter-of-fact manner.

Important as the subject of residual phosphorus is, the bulletin is a more desirable addition to the I.C.A.R.

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INTRODUCTION

Phosphorus is an important nutrient for good growth of crops. The research work done so far on phosphate fertilisation of soil has almost been confined to the assessment of its direct effect on crop yield and phosphate availabity. The problem of the phosphorus availability in the soil requires consideration in context with (a) the small amount of phosphorus present in the soil, (b) the availability of native phosphorus within short range about the neutral soil reaction and (c) a marked fixation of added phosphate. Of these the latter two, namely, increasing the availability of native soil phosphorus and the retardation of fixation on reversion of added phosphate are problems of great practical importance in soil management.

Organic and inorganic sources of phosphorus occur in soils. Inorganic phosphorus exists either in combination with calcium and magnesium or in combination with iron and aluminium. The calcium compounds in order of solubility are mono-calcium phosphate [$Ca(H_2PO_4)_2$], dicalcium phosphate [$CaHPO_4$], tricalcium phosphate [$Ca_3(PO_4)_2$], Hydroxy apatite [$3\,Ca_3(PO_4)_2\,CaO$]; carbonate apatite [$3Ca_3(PO_4)_2\,CaCO_3$] and Flour apatite [$3\,Ca_3\,(PO4)_2\,CaF_2$]. The iron and aluminium phosphates are compounds of silica and are extremely insoluble. Under moderate acid conditions silicate minerals such as Kaolinite, montmorilinite and illite fix phosphorus. This reaction of anion exchange is a reversible process. Liming reduces the fixation of the phosphates as iron and aluminium compounds to a marked degree. The organic sources of phosphorus in the soil are largely phytin and nucleic acid. In acid soils they are rendered insoluble. Under alkaline conditions calcium phytate is precipitated and thus phosphorus is rendered unavailable.

The conversion of the soluble phosphate to less soluble forms implies that this process reduces the amount of phosphate that plant roots can absorb. On calcareous soils, for instance, the precipitated calcium phosphates were believed to be more slowly absorbable than the freshly added water soluble phosphates, with much of the precipitated phosphate being fixed inside the clay lattices.

REVIEW

Murphy (1939), Williams (1949) and Russel (1950) held that the residual value of applied phosphates is the greatest in neutral soils, somewhat less in alkaline calcareous soils and the least in acid soils particularly those high in sesquioxides and kaolinite.

Stanberry (1948) studied the residual value of applied phosphates in a calcareous Sagemoor fine sandy loam and found residual effect to alfalfa of a moderate application of phosphate fertilizer after five years. Lewis *et al.* (1951) observed that the crops utilized a portion of the residual phosphate on Idaho soils. Russell (1950) reported a residual response by alfalfa on neutral and acid soils for three years following an application of 100 lb. P_2O_5 per acre. Volk (1945) found that cotton responded to residual phosphate, from five previous annual applications of 60 lb. P_2O_5 per acre as superphosphate, for a period of seven years. Williams (1950) noted crop responses to 200 lb. P_2O_5 per acre for two years following the application of fertilizer phosphate to the soil. Pot measurements of the residual value of field applications indicated that efficiency of one year old residues was 50 per cent as great as that of freshly added superphosphate. Welch and Nelson (1952) showed that the phosphate fertility level of North Carolina soils has greatly increased as a result of heavy phosphate applications on potato, tobacco and cotton producing areas. The utilization of applied phosphate in one crop on calcareous soils was shown to be less than 10 per cent; considerable amounts of residual phosphate may thus be expected to accumulate under good soil management practices.

In certain instances, the residual effect may be extremely low even with large applications of phosphorus. Mc Auliffe *et al.* (1950) reported that the applications of 1,000 and 2,000 lb. per acre of 20 per cent superphosphate to two silt loam soils in New York in 1941 showed very small residual effects in 1949, as reflected in growth and phosphorus uptake from the soil by oats and by soil tests for available phosphorus. Williams (1950) also noted large losses in the effectiveness of superphosphate applied to acid soils. In other instances, however, the residual or cumulative effects from the past application of phosphorus have been found appreciable. (Rich *et al.*, 1947; Pierre, 1938; Bushnell, 1950; Volk, 1945; Reech, 1945; Robinson and Pierre, 1938; Weeks and Miller, 1948).

The accumulation of phosphorus has been studied by several

investigators (Bryan, 1933; Hawkins, 1946, Hawkins *et al.* 1947; Peech, 1939, 1946; Verma 1956). Soils utilised in production of heavily fertilized crops showed 10 to 20 times higher available phosphorus than the virgin soils. The availability of the accumulated phosphorus is said to be rather high (Bryan, 1933; Volk, 1945; Hawkins *et al.* 1947). Volk reported that plots receiving 0, 30, 60, 90 and 120 lb. P_2O_5 annually for the initial 5 years, increased 463, 276, 91, 84 and 67 lb. of seed cotton per acre respectively when a dose of P_2O_5 30 lb. was applied uniformly during four subsequent years. These results indicate that like on soils of high native phosphate fertility when phosphate accumulations are large, the response to phosphate fertilizers becomes small. A 40-year study at the Virginia Agricultural Experimental Station (Moschler *et al.*, 1957) showed that out of an annual application of 70 lb. P_2O_5 per acre as superphosphate and rock phosphate in corn-wheat-hay-hay rotation about three-fourths of all the added phosphate remained in the soil. Chemical tests showed that (i) more of the superphosphate had reacted with the soil than had rock phosphate; (ii) more of the superphosphate-phosphorus had accumulated in the silt and clay fractions of soil and was available for plant use; and (iii) more of the phosphorus from rock phosphate had accumulated in the sand fraction of the soil and was unavailable for plant use. X-ray studies indicated that apparently some of the rock phosphate was still in its original forms.

Kurtz (1953) observed, "contrary to the apparent belief of two decades ago, more recent evidence indicates that the reactions of phosphate with soils are not irreversible and that for most soils the term 'fixation' is an exaggeration." There is a definite residual value of the applied phosphate after what has been recovered by the first crop. In the acid and neutral soils, the added phosphate quickly reacts and changes in an adsorbed form which can be readily utilised by the majority of crops. As the time passes this adsorbed form is gradually converted to less soluble form in the shape of various minerals which are less soluble in soil solution. The residual value of the applied phosphate is highest in neutral soils; it is somewhat less in alkaline calcareous soils and least in acid soils

IMPORTANCE OF RESIDUAL EFFECT STUDIES

In many countries, value of the previous phosphorus applications is ignored in determining the relative response to nitrogen or potash, principally because there is very little basis for evaluating the residual effect in terms of magnitude and duration of expected crop yield increases. This causes serious obstacle in adequate and

efficient use of fertilizers on many farms. The British farmers have since long recognised the importance of the residual value of fertilizers and have adopted a system of compensating the tenant for the fertilizer left unused in soil at the expiry of his tenancy (Smalley, 1938). According to this system a tenant when he leaves a farm, is given credit for all the improvements he has made including the improvement in soil fertility. Tables are prepared showing the value of various fertilizers remaining in the soil, after the first second and third crops are removed. In the case of superphosphate, for instance, it is estimated that two-thirds of the value remains after the first crop and one-third after the second crop. In the case of mixed fertilizer it is estimated that one third of the value remains after the first crop, one sixth after the second crop and none after the third crop. Such a system tends to encourage the tenant farmer to maintain the productivity of the soil. The magnitude and duration of the residual effect further enables one to make a proper apportionment of the cost of fertilizer in the first and the subsequent crops.

Dean (1938) studying the residual phosphate in Rothemsted and Woburn plots observed that the residual fraction amounted to 40 per cent of the total phosphorus. This proportion had more or less remained unchanged during 50 years of cropping and fertilization. Williams (*loc. cit.*) in pot studies observed that the efficiency of one-year-old residues, of 200 lb. P_2O_5 applied to the soil, was 50 per cent as great as that of freshly added superphosphate. Olsen *et al.* (1950) have shown that one crop on calcareous soils utilises less than 10 per cent. They, therefore, inferred that residual phosphate must be accumulating under good soil management practices. Olsen (1952) developed a technique to determine the residual value of phosphate in the soils. He has shown that most of the residual phosphate is present in very finely divided particles and is in the adsorbed state as "surface phosphate". The technique proposed by Fried and Dean (1952) to evaluate the availability of soil phosphorus appears promising as a measure of determining both the magnitude and duration of residual effects from previous phosphorus applications.

In Great Britain, it is a general experience that a phosphate which is inferior in immediate effects also remains inferior in its residual effects. This is particularly so with the basic slags. Those slags which have low citric acid solubility are inferior both in immediate and residual effects. The residual effects of phosphate dressings are considerably greater in soils derived from old red sand-stone than that of granitic origin (Stewart, 1953).

WORK DONE IN INDIA

In India, most of the experiments with phosphatic fertilizers have been conducted with a view to assess their efficiency in respect of the yield of immediate crop. Results reported by Panse (1952); Sethi, Ramiah and Abraham (1952); Aggarwal and Verma (1951); Yates, Finney and Panse (1953); Mukerjee (1955); Mukerjee (1956), Rege (1956) and those from Indo-American Fertilizer Use Project (1954-56) all have laid emphasis on the importance of soil type in relation to response to phosphate fertilizers. Most of the soils respond to the additions of phosphatic fertilizers, the only exceptions are the soils which contain large amounts of total as well as available phosphorus or where large amounts of iron and aluminium are present which tend to fix the phosphorus in a relatively unavailable form. In general, the red and laterite soils have a higher ratio of iron and aluminium to silica in their colloids than most of the black cotton and alluvial soils.

In India till 1944, practically no information was available about the relative efficiency of the residual phosphate to crops after the first year of application. Results of fertilizer experiments conducted under the Indo-American Fertilizer Use Project and those reported by the Indian Agricultural Research Institute, New Delhi and the States are presented in this review with the object of reorienting the views about phosphate fertilization of crops.

(i) *Direct and residual effect of graded levels of phosphate in cereal rotations* : Direct and residual response of 20 and 40 lb. P_2O_5 per acre application were studied at seven centres representing different soil types in paddy-paddy rotation. The fertilized paddy crop as well as the unfertilized succeeding paddy crop were benefited by the phosphate applications. Direct and residual extra yields (response) are given in Table I.

The average direct and residual response in paddy yield, gross and net income from fertilization and the apportionment of the cost of fertilizer between the first and the second crop of paddy are presented in Table II.

With paddy the direct response at seven centres representing different types of soils in the States of Andhra Pradesh, Mysore, Madras, Orissa, Madhya Pradesh and West Bengal to doses of 20 and 40 lb. P_2O_5 were 3.96 and 4.90 maunds of paddy per acre and the residual responses were 2.16 and 3.47 maunds per acre respectively. These centres represent some of the most phosphate deficient soils of the country. The results show that with an application of 20 lb. P_2O_5 to soil, 65 per cent of the cost of phosphate should

TABLE I. DIRECT AND RESIDUAL RESPONSE OF PADDY TO PHOSPHATE APPLICATIONS TO VARIOUS SOIL TYPES IN MAUNDS PER ACRE

Rotation : Paddy-paddy

(Results from Indo-U.S.A. Fertilizer Use Project)

Centre	Soil type	20 lb. P_2O_5		40 lb. P_2O_5		Year
		Direct	Residual	Direct	Residual	
Maruteru (Andhra Pradesh)	Red loam	5.51	4.33	9.06	4.33	1953-54
Warangal (Andhra Pradesh)	Red loam 1 year	4.30	0.14	3.39	4.61	1955-56
	2 ,,		1.45		2 71	
Aduthurai (Madras)	Coastal alluvial 1 ,,	2.59	1.17	1.79	1.06	1955-56
			0.07		1.38	
Shimoga (Mysore)	Red gravelly	1.36	0.60	3.25	2.06	1954-55
Bhagwai (Madhya Pradesh)	Medium black	8.90	5.89	14.56	7.63	1955-56
Sahaspur (Orissa)	Red alluvium	2.66	3.01	2.01	3.24	1955-56
Burdwan (West Bengal)	Recent alluvium 1 year	2.36	0.11	0.24	1.13	1955-56
			2.73		1.53	
Mean		3.96	2.16	4 90	3.43	

be charged to the first crop and 35 per cent to the succeeding paddy crop. These percentages were 59 and 41 for 40 lb. P_2O_5 dressed to the soil. On an average about 60 per cent and 40 per cent of the cost of phosphate should be charged to the immediate and succeeding crops of paddy for doses varying from 20 to 40 lb. P_2O_5 as superphosphate per acre on soils which are highly responsive to phosphate fertilization.

Superphosphate applications at 40 and 80 lb. P_2O_5 per acre to maize showed appreciable direct response and residual response in wheat at the Indian Agricultural Research Institute, New Delhi. The results are represented in Table III.

Doses of phosphate at 40 and 80 lb. per acre applied to maize effected increases in yield to the extent of 2.93 and 2.39 maunds whereas the residual responses in the succeeding wheat crop were 1.51 and 4.28 maunds per acre respectively. Somehow the direct response at 80 lb. was low. In the case of residual response being

TABLE II. AVERAGE DIRECT AND RESIDUAL RESPONSE, NET PROFIT AND APPORTIONMENT OF FERTILIZER COST IN PADDY-PADDY ROTATION

(Results from Indo-U.S.A. Fertilizer Use Project)

Particulars	20 lb P_2O_5/acre		40 lb. P_2O_5/acre	
	Direct	Residual	Direct	Residual
Mean extra out-turn (in mds. per acre)	3.96	2.16	4.90	3.43
Cash value of the extra produce at Rs. 12.00 per md. of paddy	47.52	25.92	58.80	41.64
Cost of fertilizer per dose at Re. 0.61 per lb. of P_2O_5	12.20		24.40	
Net profit due to phosphate fertilization	61.24		76.04	
Percentage cost of fertilizer chargeable to fertilized and residual crops	64.70%	35.30%	58.54%	41.46%
Average percentage cost of fertilizer chargeable for doses of 20 to 40 lb. P_2O_5 per acre	Direct 61.62%		Residual 38.38%	

TABLE III. DIRECT AND RESIDUAL RESPONSE, VALUE OF THE EXTRA PRODUCE AND APPORTIONMENT OF PHOSPHATE FERTILIZER COST IN MAIZE—WHEAT ROTATION AT I.A.R.I., NEW DELHI 1949-50 TO 1953-54

Soil Type : Alluvium (Calcareous deficient in phosphate)

Particulars	Direct Maize		Residual Wheat	
	40 lb. P_2O_5/acre	80 lb. P_2O_5/acre	40 lb. P_2O_5/acre	80 lb. P_2O_5/acre
Extra yield of grain in mds. per acre	2.93	2.39	1.51	4.28
Extra yield of straw (in mds. per acre)	5.86	4.78	3.02	8.56
Value of extra produce (in Rs. per acre)	44.68	36.35	30.95	87.74
Percentage of fertilizer (in Rs. per acre)	59.08	29.29	40.92	70.71
Cost of fertilizer (in Rs. per acre)	24.40	48.80		
Net profit due to phosphate fertilization in Rs. per acre	40 lb. P_2O_5 51.23		80 lb. P_2O_5 75.29	

4.28 maunds, the direct response should have been in the neighbourhood of 8.3 maunds, the basis of responses indicated with 40 lb. dose of P_2O_5 per acre. The residual response due to 40 lb. P_2O_5 dose was about 50 per cent of the direct response and that due to 80 lb. P_2O_5 about 180 per cent of the direct response, which, as explained above, appears to be excessive.

Based on the cash value of the additional produce due to phosphate fertilization, the cost of fertilizer to be charged to maize works out to about 60 per cent and 20 per cent for doses of superphosphate at 40 and 80 lb. P_2O_5 per acre respectively. The rest of the cost is debitable to wheat. It will thus be noted that when small doses of phosphate are applied, the main crop benefits more than the succeeding unfertilized crop.

(ii) *Direct and residual effect of phosphate applied to legume in rotation*: A series of experiments conducted at the Indian Agricultural Research Institute, New Delhi since 1940-41 have demonstrated that phosphate fertilization of berseem (*Trifolium alexandrinum*) gives a very high direct response as well as residual response on crops grown without fertilization in the rotations. Similar results have been observed at the B. R. College, Agra. The very high residual response in these experiments is partly accounted for by the symbiotic nitrogen fixed by the legume and partly by residual phosphorus readily available to the succeeding crops. Data from some of these experiments are given in Table IV.

Application of superphosphate at 132, 198 and 264 lb. P_2O_5 per acre to berseem increased the yield of green fodder by 175.3, 217.0 and 207.0 maunds respectively. In this trial, the berseem crop was fertilized and rotated with unfertilized crop of cowpea consecutively for three years. After that the land was sown with wheat for three years without any fertilization. The residual effect was shown by increased yields of wheat by 9.9, 14.1 and 15.2 maunds per acre in response to the graded doses of 132, 198 and 264 lb. P_2O_5 per acre respectively. Evaluating the extra produce and charging the cost of phosphate at the post-war price, the dose of 198 lb. P_2O_5 per acre was found to be most remunerative.

Results reported from B.R. College, Agra (Table V) show that an application of 198 lb. P_2O_5 per acre to berseem rotated with wheat was the most remunerative dose.

In fact, the variation in net profit amongst the various doses of phosphate applied to berseem crop is small. In view of this a dose of 66 lb. of P_2O_5 appears to be optimum.

Low doses of phosphate at 16, 32 and 64 lb. P_2O_5 per acre effected a corresponding increase in the yield of berseem green fodder

TABLE IV. DIRECT AND RESIDUAL RESPONSE OF HIGH LEVELS OF PHOSPHATE AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI (1940-41 AND 1945-46) (PARR AND BOSE 1947)

Soil Type : Alluvium (Calcareous deficient in phosphate).

Particulars	Doses of P_2O_5/acre		
	132 lb.	198 lb.	264 lb.
Extra yield of berseem green fodder (in mds.)	175.3	217.0	207.0
Extra yield of wheat grain due to the residual effect of phosphate	9.9	14.1	15.2
Extra yield of wheat *bhusa* due to the residual effect of phosphate at Rs. 2.5 per md.	19.8	28.2	30.4
Value of extra produce of berseem at Re. 1/- per md.	175.3	217.0	207.0
Value of extra produce of wheat grain at Rs. 15/- per md. and *bhusa* at Rs. 2.5 per md.	198.0	282.0	304.0
Total value of extra produce (in Rs.)	373.3	499.0	511.0
Cost of fertilizer at Re. 0.61 per lb. of P_2O_5	80.52	120.78	161.04
Net profit due to fertilization	292.78	378.21	349.96
Percentage of fertilizer cost chargeable to berseem	46.95	43.48	40.51
Percentage of fertilizer cost chargeable to wheat	53.05	56.52	59.49

and seed, and also benefited the succeeding crop of wheat as indicated in Table VI.

The direct reponse of the graded levels of phosphate at 16 32 and 64 lb. P_2O_5 per acre was 138.9, 220.5 and 319.1 maunds in case of berseem green fodder and 1.41, 2.23 and 2.48 maunds in the case of berseem seed respectively. The residual response shown in wheat yield was of the order of 1.80, 3.00 and 6.80 maunds, indicating increased residual effect with increasing levels of phospate. The net profit per acre to phosphate fertilization showed similar trend as seen in crop yield—a greater percentage of the benefit of fertilization is recovered in the berseem crop.

The residual effect of phosphate applications to berseem was

TABLE VII. DIRECT AND RESIDUAL RESPONSE OF PHOSPHATE IN BERSEEM-MAIZE-WHEAT ROTATION AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI (1947-48 TO 1949-50)

	Average of two cycles of the rotation		Soil type
	80 lb. P_2O_5 per acre	160 lb. P_2O_5 per acre	
Extra yield of berseem green fodder (in md./acre)	310.14	362.41	Alluvium (calcareous deficient in phosphate)
Extra yield of wheat grain due to residual effect of fertilizers (in md./acre)	5.36	5.06	
-do- wheat straw	10.72	10.12	
Value of extra yield of berseem green fodder at Re. 1.00 per maund	310.14	362.41	
Value of extra yield of wheat and *bhusa* at Rs. 2.50 per maund	107.20	101.20	
Total value of extra produce (in Rs./acre)	417.34	463.61	
Cost of fertilizer at Re. 0.61 per lb. of P_2O_5	48.80	97.60	
Net profit due to phosphate fertilization	368.54	366.01	Average
Percentage of fertilizer cost chargeable to berseem	71.90	78.18	75.04
Percentage of fertilizer cost chargeable to wheat	28.09	21.82	24.96

(iii) *Relative performance of different forms of phosphate* : Different forms of the phosphatic fertilizers, namely ammonium phosphate, superphosphate, basic slag and bonemeal were applied to berseem and residual effect was studied on maize and wheat. The yields due to direct and residual effect are tabulated in Table IX.

Ammonium phosphate and superphosphate showed the best response.

Unlike the results reported from Indian Agricultural Research Institute, New Delhi, the direct and residual effects of ammonium phosphate, superphosphate and bone-super singly and in combination at 100 lb. P_2O_5 per acre applied to Berseem in rotation with wheat at Kanpur were not significant. The data have been given in Table X.

TABLE VIII. DIRECT AND RESIDUAL RESPONSE OF PHOSPHATE APPLIED TO BERSEEM IN A THREE-YEAR ROTATION BERSEEM-MAIZE-BERSEEM-COTTON-WHEAT ROTATION AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI

(Average of 3 cycles 1948-49 to 1956-57)

Phosphate applied to the first crop of berseem at 120 lb. P_2O_5 per acre	Direct effect	Residual effect on crops in rotation			
	Berseem	Maize	Berseem	Cotton	Wheat
Extra yield due to phosphate fertilization in (md./acre)	424.71	3.4	234.6	2.4	4.8
Cash value of extra produce in (Rs.)	424.7	33.9	234.6	48.20	71.55
Total cash value of extra produce in (Rs./acre)			812.95		
Cost of fertilizer in (Rs./acre)			73.2		
Net profit due to phosphate fertilization per acre per cycle in (Rs.)			739.75		
Apportionment of fertilizer cost expressed as percentage of total cost	52.25	4.17	28.85	5.93	8.80

TABLE IX. RELATIVE PERFORMANCE (DIRECT AND RESIDUAL) OF DIFFERENT PHOSPHATIC FERTILIZERS AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI (1951)

(Sen and Bains)

Treatment per acre	Yield in mds./acre					
	Green berseem	Green berseem	*Mixed grain	Green berseem	*Green maize	*Wheat
	1944-45	1945-46	1946	1946-47	1947	1947-48
No fertilizer	266.2	432.4	26.8	270.3	163.0	12.3
Superphosphate at 120 lb P_2O_5	285.3	494.0	28.6	349.8	171.2	19.4
Bonemeal 120 lb. P_2O_5	306.0	451.4	26.1	306.2	167.1	16.1
Ammo-phos at 120 lb. P_2O_5	399.2	555.2	28.7	403.7	175.3	20.0
Basic slag at 120 lb. P_2O_5	270.2	484.5	28.5	321.1	174.1	15.5

* Unfertilized crops

TABLE X. RELATIVE PERFORMANCE (DIRECT AND RESIDUAL) OF DIFFERENT PHOSPHATIC FERTILIZERS AT COLLEGE DAIRY FARM, KANPUR (UTTAR PRADESH)
(Aggarwal and Verma, 1951)

	Average yield in lb. per acre				Average of 2 years	
	Direct Berseem 1945-46	Residual Wheat 1946-47	Direct Berseem 1947-48	Residual Wheat 1948-49	Direct Berseem	Residual Wheat
No fertilizer	44,120	1,653	30,536	1,528	37,328	1,590
Superphosphate at 100 lb. P_2O_5	50,160	1,598	37,800	1,560	43,980	1,589
Ammo-phos at 100 lb. P_2O_5	58,280	1,668	38,184	1,712	48,232	1,690
Super. 75 lb. P_2O_5 + Ammo-phos. 25 lb P_2O_5	45,160	1,657	35,304	1,776	40,232	1,716
Bone superphosphate at 100 lb. P_2O_5	43,720	1,640	31,496	1,640	37,608	1,640
Super. 75 lb. P_2O_5 + Bone superphosphate 25 lb. P_2O_5	50,320	1,739	36,984	1,472	43,652	1,606

Failure of response due to phosphate fertilization at Kanpur may be attributed to the high content of available P_2O_5 varying between 0.03 to 0.05 per cent and a favourable pH (7.4) of the soil at which the soil phosphate is normally available in abundance.

For the similar doses of P_2O_5, superphosphate alone or superphosphate in combination with farmyard manure proved superior sources of P_2O_5 than farmyard manure alone as indicated in Table XI.

It will be observed that in the second cycle, the yield in the 'no fertilizer' plot was reduced to almost half of the berseem yield in the first cycle. The wheat yield, however, was not appreciably reduced. On the other hand, the berseem yields of plots dressed with P_2O_5 gave on the whole yields in the second cycle higher than the first cycle. Differences in yield of berseem treatments, 3, 4 and 5 in the two cycles were almost identical. But the wheat yields in the second cycle were lower than the first cycle.

(iv) *Role of phosphate fertilization in mixed farming units* : Phosphate fertilization of berseem, peas and cowpeas in

TABLE XI. RELATIVE PERFORMANCE (DIRECT AND RESIDUAL) OF ORGANIC AND INORGANIC FORMS OF PHOSPHATE AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI
(Parr and Bose, 1947; Sen and Bains, 1955 and 1957)

Source of phosphate	Yield of crops (in md. per acre)					
	I Cycle		II cycle		Average of 2 cycles	
	Berseem	Wheat	Berseem	Wheat	Berseem	Wheat
	Average of 3 years					
No fertilizer	169	16.5	81 (0 6)	15.7	125	16.1
F.Y.M. at 64 lb. P_2O_5	303	21.3	315 (3.1)	19.5	309	20.4
Superphosphate at 64 lb. P_2O_5	354	27.9	400 (3.1)	22.6	377	25.3
F.Y.M. at 8 lb. P_2O_5 + Super. 56 lb. P_2O_5	339	25.53	401 (3.3)	20.6	370	23.0
F.Y.M. at 56 lb. P_2O_5 + Super. at 8 lb. P_2O_5	350	25.73	404 (3.5)	20 4	377	23.0

Figures in brackets represent yeild of berseem seed.

systematically laid out small 6-acre mixed farming units at the Indian Agricultural Research Institute, New Delhi has shown considerable direct and residual response in crop production. The out-turn per acre of the principal succeeding crops of wheat and maize was increased to the extent of 32.1 per cent and 20.3 per cent respectively. The average annual production from the mixed farming units with and witout phosphate fertilizers is given in Table XII.

Annual production from the holding growing legumes in which superphosphate had been applied to Berseem, having 200 per cent cropping intensity, was found to meet the food, feeds and cash requirements of an average family unit. In the other holding where phosphate fertilization was not practised, the production was not enough to match the consumption. Net profit due to direct and residual effect of phosphate fertilization in this series works to Rs. 550.00 per annum or about Rs. 90.00 per acre. This is entirely attributed to an investment of Rs. 227.5 in the application of superphosphate. In other words every rupee invested in phosphate returned Rs. 3/- in gross profit or Rs. 2/- in net profit.

TABLE XII. OVERALL ANNUAL PRODUCTION FROM 6-ACRE HOLDINGS WITH AND WITHOUT PHOSPHATE FERTILIZATION OF LEGUMES AT INDIAN AGRICULTURAL RESEARCH INSTITUTE, NEW DELHI 1946-47 TO 1952-53

(Sen and Bains, 1956)

Items of production	Production from holding including phosphate fertilized legumes (md)	Holding including legumes without phosphate (md.)	Extra produce due to phosphate fertilization of legumes (md)	Value of surplus or deficit produce (Rs.)
Cereals	93.9	53.8	+ 40.1	481 2
Pulses	37.6	23.7	+ 13.9	166.8
Green fodder (Berseem)	871.3	557.7	+313.6	313.6
Dry fodder	262.9	155.0	+107.9	107.9
Seed cotton	3.5	4.9	— 1.4	28.0
Gur	—	30.0	— 30.0	240.0
Oilseed	—	1.6	— 1.6	24.0

Total extra value of produce from holding growing legumes fertilized with phosphate	Rs. 777.5
Cost of phosphate	Rs. 227.5
Net profit due to phosphate fertilization of legumes in crop rotation	Rs. 550.0

SUMMARY

Most of the research work on phosphate fertilization of soils had hitherto been confined to the assessment of its direct effect on crop yield and phosphate availability. Recently, a large number of field trials have been carried out by the Agricultural Departments, both in the states and at the centre to study the direct and residual effects of phosphate fertilizers. A brief summary of the results reviewed is given below :

1. Phosphate fertilization of paddy showed considerable direct and residual response. Average direct response from soils (red loam, red gravelly, medium black, red alluvium, coastal alluvium and recent alluvium deficient in phosphate)

for 20 and 40 lb. P_2O_5 was 3.96 and 4.90 maunds of paddy per acre respectively. The residual responses were 2.16 and 3.47 maunds of paddy for the same doses. Thus 60 per cent of the cost of fertilizer is chargeable to the first crop of paddy and 40 per cent to the succeeding one for doses varying from 20 lb. to 40 lb. P_2O_5 per acre.

2. In the maize-wheat rotation tests carried out on alluvial (calcareous deficient in N and P) soil, for 40 lb. P_2O_5 per acre dose, 60 per cent of the benefit was derived by maize crop and 40 per cent by the succeeding crop of wheat.

3. On the alluvial soil (calcareous deficient in phosphate), appreciable residual responses on the succeeding crops have been noticed in crop rotations in which berseem was grown on soils dressed with phosphate. Increasing doses of phosphate showed correspondingly increased direct and residual effects. The magnitude and the duration of the residual effect, however, varied with the soil condition and cropping sequence. The experimental evidence from a number of field trials indicates that about 50 per cent of the cost of phosphate may be charged to the berseem crop which exhibited direct response and the rest to the crops grown in the sequence for doses varying from 60 to 120 lb. P_2O_5 per acre.

4. Among the different forms of phosphates tried, ammonium phosphate and farmyard manure were superior sources of phosphate than F.Y.M. alone as a source of phosphate direct and residual response.

5. In a six-acre holding, having 200 per cent intensity of cropping, application of Rs. 227.5 worth of phosphate to legumes resulted in gross profit of Rs. 777.5. Thus every rupee invested in superphosphate returned Rs. 3/- in gross profit or Rs. 2/- in net profit.

In general, these results conclusively point to the fact that due consideration should be given to the residual effect of phosphate fertilizer applications both in charging the cost and formulating a fertilizers schedule for the succeeding crops.

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